Identification of abiotic and biotic factors in the diet of groundfish in the Gulf of Alaska

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Background

Successful integration of ecosystem processes into management of marine resources requires a working knowledge of system behavior and an ability to represent an ecosystem accurately in a modelling framework. The Bering Sea and Gulf of Alaska support a diversity of species and fisheries, and have been the subject of a variety of modelling approaches to explore species interactions and community dynamics. Modelling efforts thus far have focused on species interactions as a method of generating hypotheses and predictions regarding interacting fisheries and changes in populations. However, these models lack inputs from physical parameters of the system and biotic interactions outside of productivity, predation, and competition. Climate regimes and, by proxy, species distributions and interactions, are increasingly uncertain (Kennedy et al. 2002); the inclusion of some of these parameters can increase understanding of a complex system in a changing environment.

There have been a few attempts to incorporate ecological interactions into stock assessments for Alaskan fishes. Models for walleye pollock (*Theragra chalcogramma*) have included modified natural mortality, *M*, based on the abundance of predators (Livingston 1998; Hollowed et al. 2000). Multispecies virtual population analysis has been applied to the Bering Sea (Livingston and Jurado-Molina 2000) as well as the Gulf of Alaska (Van Kirk 2008). Similar to the single species assessment, these models are focused on walleye pollock dynamics and a few interacting predators. At the system scale, full ecosystem models have also been constructed in the mass balance-based Ecopath with Ecosim (EwE) framework for the Bering Sea, Gulf of Alaska, and Aleutian Islands (Aydin et al 2007). These EwE models have yielded insight into the differing trophic dynamics and energy transfer of these systems but do not incorporate environmental factors outside of primary productivity estimates (Aydin et al. 2007).

Interestingly, these approaches have a similar constraint. Predation rates of each predator on each prey are determined independently, using diet data and information on population dynamics. While each predator has a unique consumption rate on a prey item, these models are structured so that consumption rates of each predator respond only to available density of prey. This is assumed to be similar to a Holling Type II functional response (Hollowed et al. 2000). However, recent studies have shown that multispecies model outputs such as biomass estimates of prey species are sensitive to the functional response used to describe predator foraging rates (Kinzey and Punt 2009; A'mar et al. 2010). These results indicate that further investigation into the factors affecting foraging rates are important to understand to better represent species interactions within a multispecies modeling framework.

There is ecological evidence that suggests a variety of both abiotic and biotic factors may affect foraging rates of predators in addition to prey density. One such factor, temperature, is a ubiquitous aspect of the environment that may influence trophic interactions significantly. In addition to direct effects on growth rates and metabolic demands of predators, temperature changes can impact behaviors. Movement and activity rates have been shown to be sensitive to temperature in both pelagic (Hurst 2006) and demersal (Hurst and Duffy 2005) prey species. Activity and movement are important in bioenergetics models (Brandt 1993), but also affect encounter rates and probability of capture success, important factors in modeling predator-prey dynamics (Peck et al. 2006; Hurst 2006). In addition, temperature is an important factor regulating seasonal and interannual variation in species distribution. Differential responses among species may alter the degree of overlap between a predator and specific prey item. Similarly, temperature-driven spatial shifts may be a factor in the amount of niche overlap between competitors (Magnuson et al. 1979; Attrill and Power 2004). Therefore, temperature can be used as a proxy for spatially-explicit variance in predatory responses.

Other abiotic factors, such as the physical structure and complexity of habitat, can also influence predator prey dynamics. Multiple studies have shown fish prey species altering behavior and correlated higher survival rates with increasing habitat complexity at the small scale in freshwater, as well as in reef environments (Persson and Elkov 1995; Tupper and Boutilier 1997). Similar trends have been demonstrated from a predator's perspective, indicating differing foraging success of predatory fish among habitat types (Crowder and Cooper 1982; Beukers and Jones 1997).

Biotic factors can alter predator-prey dynamics as well. In the current modelling frameworks for Alaskan ecosystems, two predators that share prey are by definition competitors. However, non-additive predation effects, where a species may increase predation on another species through competition for space or other behavioral mechanisms, have been noted in the ecological literature, with examples including fish (Harvey et al. 2003) and marine systems (Siddon and Whitman 2004).

Investigation of important abiotic and biotic factors in the diet of key species in a system may improve our ecological knowledge of the system while identifying mechanisms that drive the foraging responses used in multispecies models. In this study we propose to use time series abundance and diet data collected by the Alaska Fisheries Science Center (AFSC) in the Gulf of Alaska to: 1) determine the role of abiotic and biotic factors in diet indices in 3 overlapping groundfish predators (cod, halibut and sablefish) and 2) incorporate these empirical observations into a multispecies model.

More specifically, the objectives of this study are to:

- Determine the effect of temperature or habitat type on prey weights, prey size, and overall diet composition

- Determine whether the effects of presence and density of potential competitors are correlated with prey composition or consumption rates and, if so, determine whether these effects are non-additive
- Determine if observed effects of abiotic and biotic factors vary by spatial scale
- Incorporate temperature and biotic factors into the functional responses of predators in a multispecies modelling framework and compare against previous models

Approach

The AFSC has been conducting standardized groundfish trawl surveys of the GOA triennially since 1984 and biennially since 1999 (von Szalay 2010). Abundance data from these surveys have been an important part of the stock assessments of key groundfish in the system. Furthermore, over 300,000 stomachs have been analyzed from 90 species since 1985 (AFSC 2009). These data have been used to develop the previously cited ecosystem models for the GOA. In addition, data on the physical parameters of each tow are available including temperature, depth, and habitat type. This project will use this previously collected data on three important groundfish predators: Pacific cod (*Gadus macrocephalus*), Pacific halibut (*Hippoglossus stenolepis*), and sablefish (*Anoplopoma fimbria*). All of these species share some dietary overlap and all consume varying levels of pollock, an important ecosystem link and commercial fishery.

Determination of abiotic and biotic factors in groundfish diets

Using the diet database and data available on the physical characteristics of the tows where the stomachs were collected on the GOA survey, we can link the prey composition and diet indices to those physical parameters. These links can be examined independently for each predatory species across temperature as well as ontogeny, informing the diet through age structure. Stomach samples can be aggregated at differing levels of spatial resolution. Statistical methods to be used include:

- A multivariate analysis (non-metric multidimensional scaling, NMDS) of diet composition based on predator size, water temperature, and habitat type.
- General additive model of factors determining the contribution of specific prey items to predator diets based on the same independent variables.
- General additive model to determine if prey size is affected by any physical parameters, with particular attention to pollock and the other predatory species.
- Similar tests exploring the potential response to the presence or density of the other predatory species.
- All relationships will be investigated at different levels of spatial aggregation: the fine scale (survey strata), regional scale (east, central and west GOA), and full system scale (entire GOA).

Modelling questions and approaches

Our modelling questions follow after our statistical analysis. If abiotic or biotic effects are identified from the data, these can be incorporated into a multi-species modelling framework. The approach used will be an age-structured model including the three groundfish predators as well as a prey species, walleye pollock. The model to be used allows for predator-predator interactions as well as predator-prey, following Kinzey and Punt (2009). Alternative forms of the predation functional response can and have been incorporated into this modeling structure. We will extend this by including physical parameters as mechanistic drivers of species interactions. Temperature and habitat effects can be incorporated to influence individual functional responses by increasing or decreasing consumption rates as a function of temperature (Flinn 1991) or habitat type. Similarly, nonlinear predation effects can be incorporated as a multi-species functional response (Soluk 1993).

Biomass estimates over time for all species will be calculated using survey abundance data and catch data as well as the traditional functional responses (Holling Types I, II, III) and novel forms that incorporate abiotic factors or alternative biotic interactions as guided by the results of the statistical analysis. These results will indicate model sensitivity to the incorporation of the alternative functional forms and data sources. If no significant relationships are found in the statistical analysis, the same modeling framework will be used in a more heuristic approach. Abundance data will be used similarly to predict biomass with inputs from predation using the traditional functional responses as well as conduct analysis using novel predation forms that incorporate physical parameters. Under this scenario, the results of our multispecies modeling analysis will still indicate the sensitivity of these models to novel foraging responses, but might not be as representative of system dynamics.

Roles of Primary Personnel
Principle investigators will work collaboratively in guiding Kevin Thompson, a doctoral student at OSU. They will have input on statistical methods, ecology, model structure, and stock assessment as this work is completed by the student, described in manuscripts for publication, and included in a dissertation.

Benefits

Importance, relevance, and applicability to FATE objectives

This research meets the goals of FATE in the inclusion of ecological and environmental data into quantitative fisheries assessments. This project is based on expanding the analysis and use of previously collected diet data within the GOA, which has been used in only limited capacities for determining consumption rates for modeling efforts. While multiple multispecies modeling frameworks have been explored in this system, abiotic environmental factors have not been included in determining predation rates by important fish species. By incorporating ecological theory not before applied in a fisheries management framework, the results of this study may yield a model that includes environmental forcing on system dynamics, a potentially valuable tool for projecting stocks into the future. Furthermore, the addition of different forms of functional responses in multispecies models may lead to new conclusions regarding the fishable biomass of prey species in the system.

Overall NMFS goals

This work will also enhance collaboration between Oregon State University and the AFSC, as well as two different divisions within the AFSC. Furthermore, this work will be the central basis of a dissertation and lead to increased ecological training and quantitative fisheries experience for a doctoral student.

Deliverables

- Presentation for FATE meeting
- Manuscript(s) addressing the relationship between temperature and species composition in the diet of groundfish predators
- A multispecies model of key groundfish in the GOA ecosystem
- Manuscript(s) detailing the construction of the above, including the species studied and new formulations of functional responses based on the statistical relationships found and the implications of including them
- A synthesis of all work, presented in a graduate student dissertation

Timeline

1-6 months	6-12 months	12-18 months
organizing and accessing data statistical analysis of temperature and biotic factors in diet data for key species	preparation of manuscript on statistical relationships identified incorporation of functional responses into multispecies modeling framework	incorporation of functional responses into multispecies modeling framework Manuscript prep Travel to FATE meeting

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